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Original article

MONITORING AIR POLLUTANTS AND DUST IN LUXOR MUSEUM OF THE ANCIENT ART

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Abstract

Air pollutants and dust affected the artifacts in Luxor museum; one of the most important museums in Egypt and the Middle East. Therefore, the present investigation is concerned with air pollutants and dust that may be affective or catalyst in the deterioration of Luxor museum's artifacts using the following technique: ***a)*** *The checker of PH used for monitoring and identifying alkaline and acidic areas inside the museum.* ***b)*** *The passive indicator device used for Ammonia and acetic acid monitored inside the museum; it is caused by the upper un cover concrete part of the walls.* ***c)*** *XRF analyses of dust samples that were collected using the sticky straps followed by digital microscope investigation. Results confirm the existence of Ammonia and acetic acid in the museum, In addition, the physical and chemical mechanism led to the current deterioration states of both wooden basses and the limestone wall of Ikhnaton's.*

Keywords: *Monitoring, Checker, Passive indicator, Degradation, Ventilation, Discoloration Salt efflorescence.*

1. Introduction

Air pollution, generally, means that there are unexpected particles pollutants with high concentration. It occurs almost everywhere and has a long history [1]. In its broad sense, a pollutant is a substance that has a detrimental effect on the environment or on something of value (including health) and is present in the atmosphere in amounts greater than natural concentrations, primarily due to human activity. Air pollutants affect Luxor museum's inorganic and organic materials; a wide range of materials, from textiles and works of art on paper to pigments and leather bindings are at risk of being damaged by gaseous pollutants [2]. Consequently, the cultural property inside the museum can be threatened either by outdoor pollutants, such as gases from car exhausts that make their way into the buildings or indoor pollutants generated from sources within the museum, such as fumes from cleaning products. In most cases, indoor-generated pollutants pose a greater risk to collections than outdoor-generated pollutants. Typically, this is because indoor sources are in close and continuous proximity to objects. All of them lead to the emergence of some aggressive pollutants such as TSP, fuels, dusts, oxides, organic materials, hydrocarbons and some effective gases i.e. CO, CO_2, SO, NO_x, HS, NH and CH_4 [1]. Naturally ventilated buildings have indoor concentrations of pollutants that are equal to the outdoor levels. However, buildings with heating, ventilation, and air-conditioning (HVAC) systems that have gas-phase filtration minimize the infiltration of pollutants, reducing the indoor level to be as low as 5 % of the outdoor concentration [2]. The most common types of outdoor pollutants are sulfur dioxide, nitrogen oxides, ozone, and reduced sulfur gases such as hydrogen sulfide. The most common indoor-generated gases are acetic acid, formic acid, acetaldehyde, formaldehyde, hydrogen sulfide, carbonyl sulfide, and ozone. They can be off-gassed from paints, boards, carpets, and cleaning materials, as well as many other materials and products. They can, also, be generated during cleaning and heating. Smoking, also, is a source of formaldehyde and other toxic compounds [3]. There are numerous numbers of reports on indoor air pollutants and material damage, for example: carbonyls and corrosion of lead, copper, or bronze, carbonyls and the degradation of paper, reduced sulphur compounds and tarnishing of silver, sulphur dioxide and/or nitrogen oxides and the degradation of leather and paper. According to Morten, 2006 [4], it could be said that the aggressive effects of air pollution on museum artifacts are created through four variables, tab. (1). They contain **(A)** *Acidic substance*. **(B)** *Alkaline substance*. **(O)** *Oxidizing substance*. **(R)** *Reducing substance*. Luxor museum lies in the heart of Luxor between Karnak and Luxor temple, on the east bank of the Nile, facing Theban necropolis. Excavations of its numerous sites resulted in a great variety of monuments and objects which were originally stored in store rooms in order to house these treasures, to protect them and to display them effectively. It was decided that a special museum should be constructed [5] Therefore, the Ministry of Culture commissioned Dr. Mahmoud El Hakim to design the museum because he was one of the leading architects in Egypt and supervised the construction of the best Egyptian museum with its fine garden rising from the corniche along the Nile that provided an ideal space displaying colossal sculptures and large blocks of carved relief. In December 1975, the museum was officially opened for the public.

Table (1) the aggressive Chemical substance of air pollution and their effects on museum artifacts

Chemical substance	Source	Influence
Ammonia (B)	Concrete, aqueous ink	Discoloration and transubstantiation
Nitrogen oxide (A)	Heating appliance, lighting .etc...	Corrosion of metal, weakening of textile and paper
Formic, Acetic acid (A)	Plywood, timber and consolidates.	Metal corrosion and discoloration of pigments
Aldehyde (R)	Plywood and formaldehyde resin	Weakening of organic materials and discoloration
Ozone (O)	Heating appliance, lighting, etc.	Oxidation and weakening of organic materials
Carbon dioxide (A)	visitors	Discoloration of pigments and deterioration of organic materials
Sulfur compounds (A)	Gum carpet	Tanning of metals

2. Technique and Method of Air Pollutants Monitoring

This part aimed to evaluate the current state of the museum's atmosphere and to minimize the risk of air pollutants affecting the museum artifacts. In addition, air pollutants inside the museum had to be controlled and archeological organic and inorganic materials had to be kept in a stable atmosphere. Our monitoring techniques (*PH and other hazardous technique*) were done according to the JICA monitoring system [6]. These targets were achieved as follows: *Monitoring the PH conditions in the air (acidic/ alkaline) and hazardous gases (Ammonia and organic acids). *Notice urgent /continuous chemical risks and their short and long term changes. *Keep a suitable and stable environment for all types of artifacts and avoid chemical degradation caused by unexpected conditions. The **1st** step was monitoring the PH conditions in the museum (acidic /alkaline). The **2nd** one was monitoring air pollutants by the passive indicator (ammonia/organic acid). The 3rd one was analyzing the results to set a strategy to avoid the influences of these pollutants on the artifacts.

2.1. *Technique of PH monitoring*

In this part, simple test (*paper checker*) was used to evaluate the acidic or the alkaline value of air according to the changes of the checker's color. The checker, which was put into liquid, contained some dyes (*i.e. chlorophenol red, bromocresol green, bromothymol blue, and phenol red*) and glycerin for solvent. Their colors changed according to the acidic /alkaline conditions after exposing to the air for 24 hours or for 48 hours if the RH was less than 40 %. After exposing time, the color of the checker had to be compared to the scale color which gave the result of the PH value of the museum's air. The researchers used **12** checkers; **6** of which were used at the old museum, on the 1st and 2nd floor, and the other **6** were used at the new extended part, on the 1st and 2nd floor. Because RH value in the museum was less than 40 %, the monitoring process was kept for 48 hours. Monitoring was conducted twice; in April and July, 2014, and the results were almost the same, fig. (1).

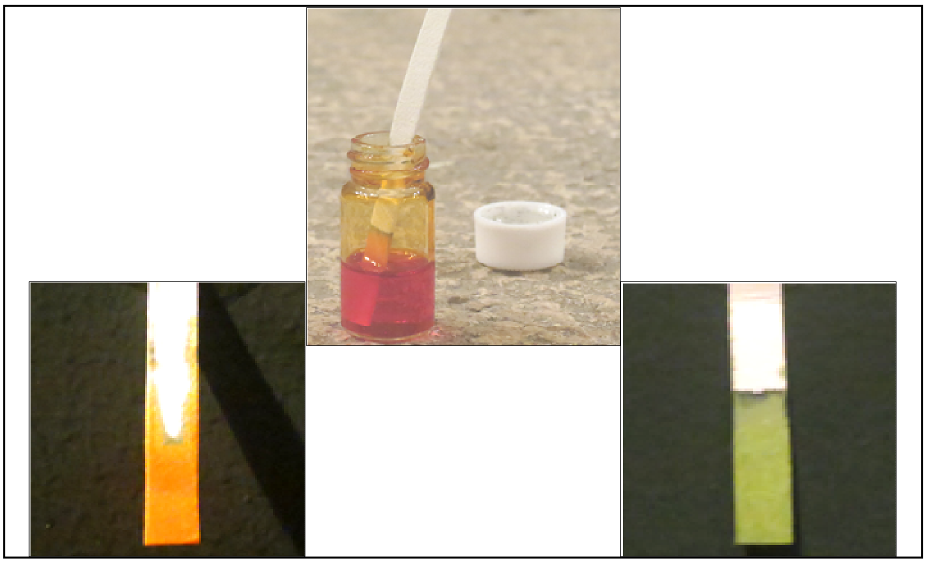

Fig. (1) Shows change of the checker color due to the PH value

2.2. *Monitoring ammonia and organic acids*

The second step was monitoring and identifying the pollutants inside the museum using the passive indicator. In this part, two device indicators; *Organic acids passive indicator* (blue) and *Ammonia passive indicator* (red) were used. Both of them depended on changing the device's color when being exposed to air, from red into discolored device for the Ammonia and from blue into discolored device in the organic acids, fig (2-a, b). The researchers used three types of passive indicators; Ammonia passive indicator within the average level of 30 ppb, then two of the passive indicators of organic acid within average level of 175 ppb and 80 ppb. Their locations were selected according to the results of PH value checker, where Ammonia passive indicator of PH value was alkaline, acids passive indicator of PH value was acidic, fig (3-a, b)

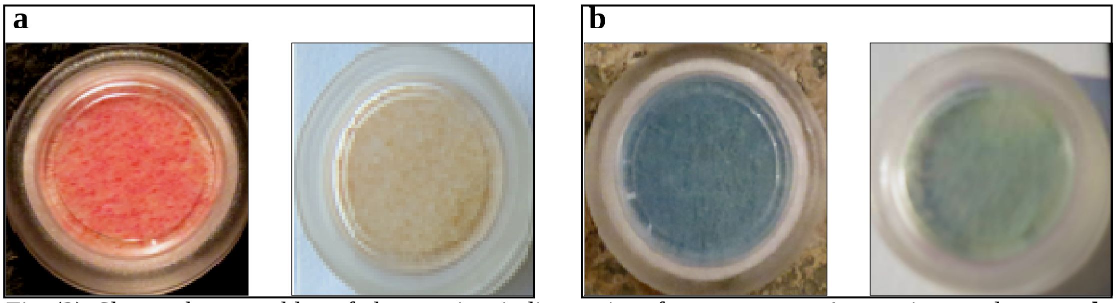

Fig (2) Shows the pamphlet of the passive indicator interference gas **a**. Ammonia gas detector, **b**. Organic acids detector

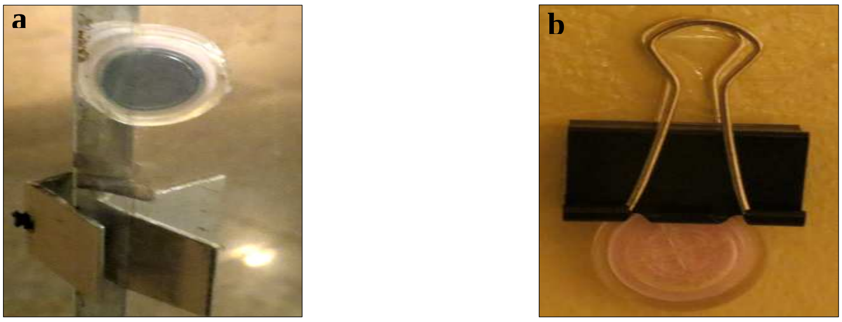

Fig (3-a, b) Shows hanging methods of the passive indicator in the museum

2.3. *FTIR analyses*

Fourier Transform Infrared Spectroscopy (FTIR) identified chemical bonds in a molecule by producing an infrared absorption spectrum [7]. The spectra produced a profile of the sample, a distinctive molecular fingerprint that could be used to screen and scan samples for many different components [8]. Some deteriorated samples, collected from wooden bases, were analyzed by *Mattson Genesis II (thermo electron Corp., Madison, WI)* FTIR apparatus to evaluate the structural changes of their physical and chemical properties. Two samples were selected; one from the wooden fibers and the other from the deteriorated parts. according to the following standards, testing was conducting: light source, detector TGS, accumulation Auto (74), resolution 4 cm, Gain auto (8), A aperture auto (7.1mm), scanning speed auto (2mm/sec), filter auto (30000 HZ).

2.4. *Monitoring the dust and the air particles by XFR*

Airborne particles are aggressive pollutants because of their composition. Dust particulates can contribute to all deterioration mechanisms and forms, such as metal corrosion or other forms of damage [9]. The current study adopted two techniques of monitoring and analyses, as follows: The first was visual monitoring through using lasting strips which were put close to the wooden bases and above the show cases. It was expected to find dust and air particles above these strips. Therefore, the 2nd technique was XFR testing of the dust sample that was collected from the previous strips and the edges of the showcases using soft smooth braches.

3. Results

3.1. *PH monitoring results*

Results showed that the PH value of air was alkaline in both times of monitoring. The stable value of PH was found in the new extended part of the museum, the mummy's room, and on the 2nd floor of the open display area. Other results suggested that most of the locations showed, almost, the same alkaline value of PH, fig. (4). When they were compared with the scale, it was clear that most of the colors were between 3-4 degrees on the scale; which was alkaline, only the 12th checker in the new extended part was between 2-3 degree on the scale; which was almost clean air.

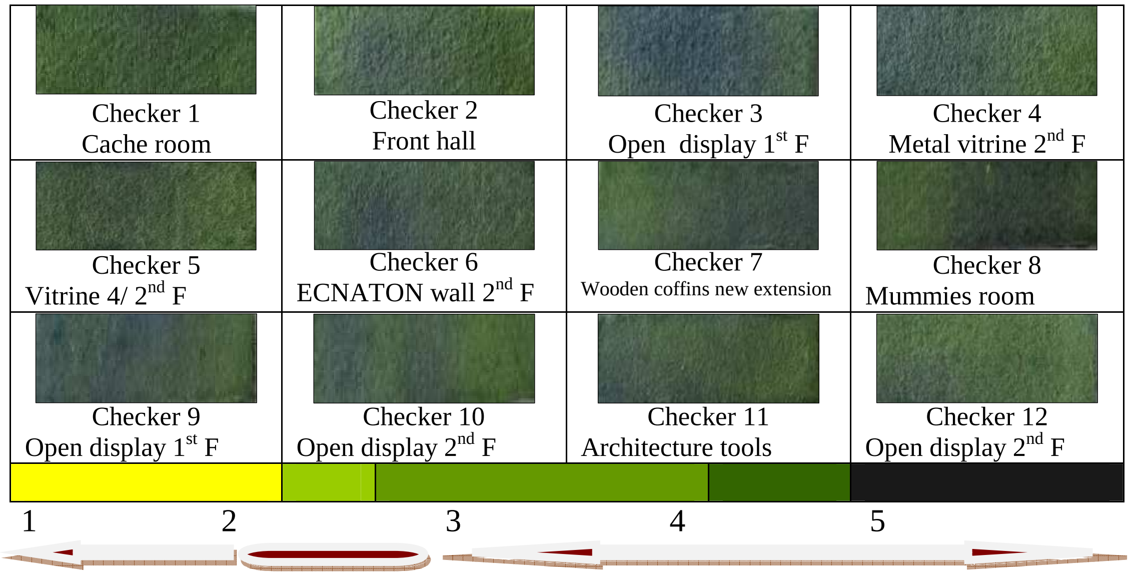

Fig (4) Shows comparing checker color with the scale

3.2. *Ammonia and organic acids monitoring results*

The recorded changes showed that there were some changes in the indicator's colors. On one hand, the color's change from red to discolor was attributed the existing of ammonia. On the other hand, color's change from blue to smoky was essentially due to the existence of organic acids, fig. (5-a, b)

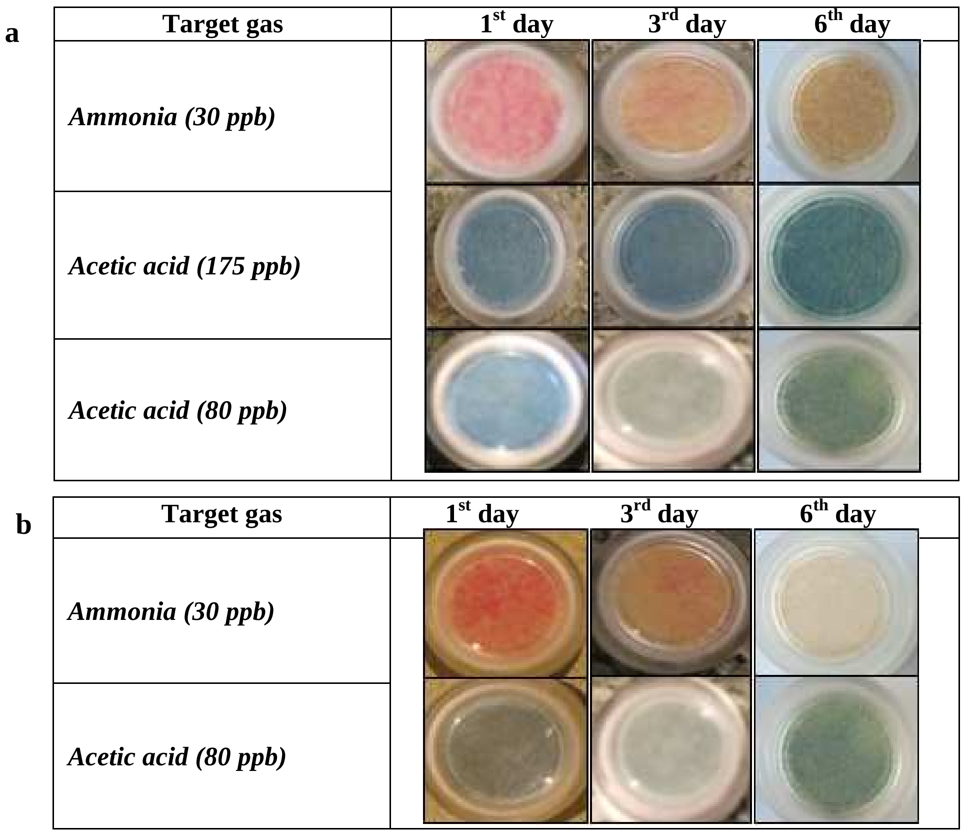

Fig (5) Shows **a**. daily recorded changes on the checker color on the old section of the museum, **b**. new section of the museum

3.3. *FTIR evaluation results*

FTIR analysis results proved that there were different compounds. In addition, bonds on wood affected the acceleration of its deterioration. Results are listed in tab. (2-a, b) & fig. (6-a, b).

Table (2-a) FTIR analytical results of wood fibers sample

NO	Functional group	Waive rang	Chart results	Comment
1	OH	3300-3400	3289.96	Broad band due to Bonded O-H stretch
2	C=O	3000-2800	2919.7	Asymmetric and symmetric C–H stretch in methyl and methylene groups
3	Lignin	1510-1590	1594.84	Aromatic skeletal vibrations of lignin (C=C stretching vibration in aromatic ring in lignin) plus C=O st
4	C-O	1000-1300	1031.73	C–H vibrations in cellulose and a C–O vibration in syringe.
5	C-O	1000- 0	70.8611	glycosides linkages, besides CH-deformation of cellulose

Table (2-a) FTIR analytical results of deteriorated parts sample

NO	Functional group	Waive rang	Chart results	Comment
1	OH	3300-3400	3291.89	Broad band due to Bonded O-H stretch
2	C=O	3000-2800	2919.7 2359.48	Asymmetric and symmetric C–H stretch in methyl and methylene groups
3	Lignin	1510-1590	1590.06 1590.02	Aromatic skeletal vibrations of lignin (C=C stretching vibration in aromatic ring in lignin) plus C=O stretch
4	C-O	1000-1300	1027.87	C–H vibrations in cellulose and a C–O vibration in syringe (a main component of lignin) derivatives.
5	C-O	1000- 500	596.861	glycosides linkages, besides CH-deformation of cellulose
6	C-H	500-0	405.942	deformation in cellulose
7	OH	3300-3400	3291.89	Broad band due to Bonded O-H stretch

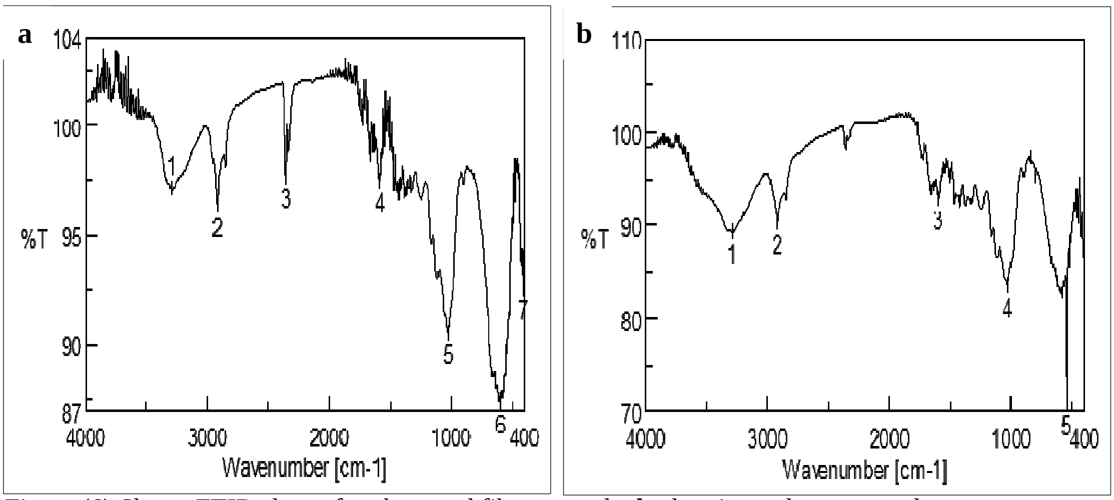

Figure (6) Shows FTIR chart of **a**. the wood fibers sample, **b.** deteriorated parts sample

3.4. *XRF evaluation results*

XRF results suggested that there were little quantities of dust within the fibers of the carpets in the museum. These might be due to daily routine cleaning and the tight doors and windows, fig (7).

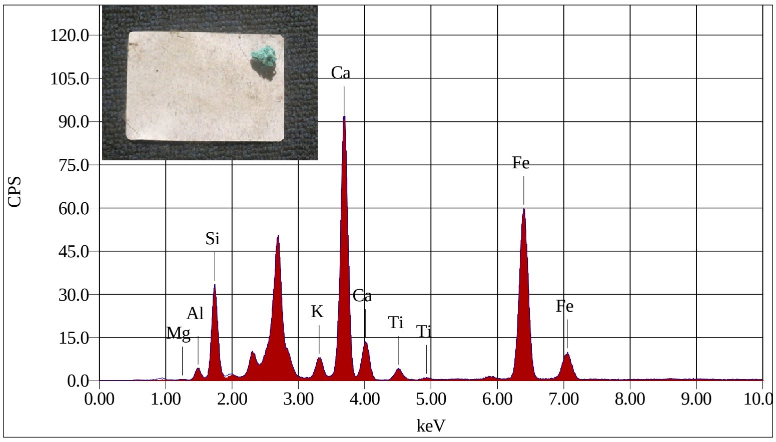

Fig (7) Shows XFR chart of little airborne dust sample collected present over the strips

4. Discussion

Results of the first step of PH value monitoring in the museum suggested that PH value in most areas was alkaline and that only two checkers gave poor evidence of the acidic PH value. Furthermore, the alkaline PH value proved the existence of gases like Ammonia and the acidic PH value of gases such as nitrogen, carbon and formic acid [4]. These led to the emission of some pollutants and different gases, e.g. CO, CO_2, SO_2 and, especially, NO_2. They played an important role in the oxidation processes. They, also, led to many deterioration effects, mechanisms "chemical and/or physical" and forms [1]. The alkaline PH value formed alkaline solutions, especially within the high RH value inside the museum. This caused deterioration of the inorganic and the organic archeological materials, such as the acceleration and degradation of lignin and hemicelluloses of wood [10]. Within the same context, monitoring ammonia and organic acids using the passive indicator, fig. (5-a, b) suggested the existence of ammonia and organic acids pollutants. In addition, the results showed that Ammonia was found inside the museum in the open display areas in the old museum; in the 1st floor and the 2nd floor. Most of the passive indicators' results were greater than the average level. This meant that there was an urgent need to treatment. On the contrary, acidic pollutants and gases in most parts of the museum were less than the average level; only two of the passive indicators were more than the average level. While the average level of Ammonia in the open display areas resulted from the upper unpainted cement [1], Concert parts above the artifacts in the old and the new parts of the museum, fig. (8). The other pollutants sources resulted from car exhaust, Luxor General Hospital, internal generators and natural ventilation.

Fig (8) Shows the unpainted concrete bars over the open display areas

The average level of the acidic pollutants inside the museum resulted from the type of carpets s used in the showcases, the MDF wooden boxes under some artifacts and air pollutants such as car exhaust, factories, fuel, dust and acidic gases which are the most deteriorating factors for the archeological wood [11], fig. (9-a, b, c, d).

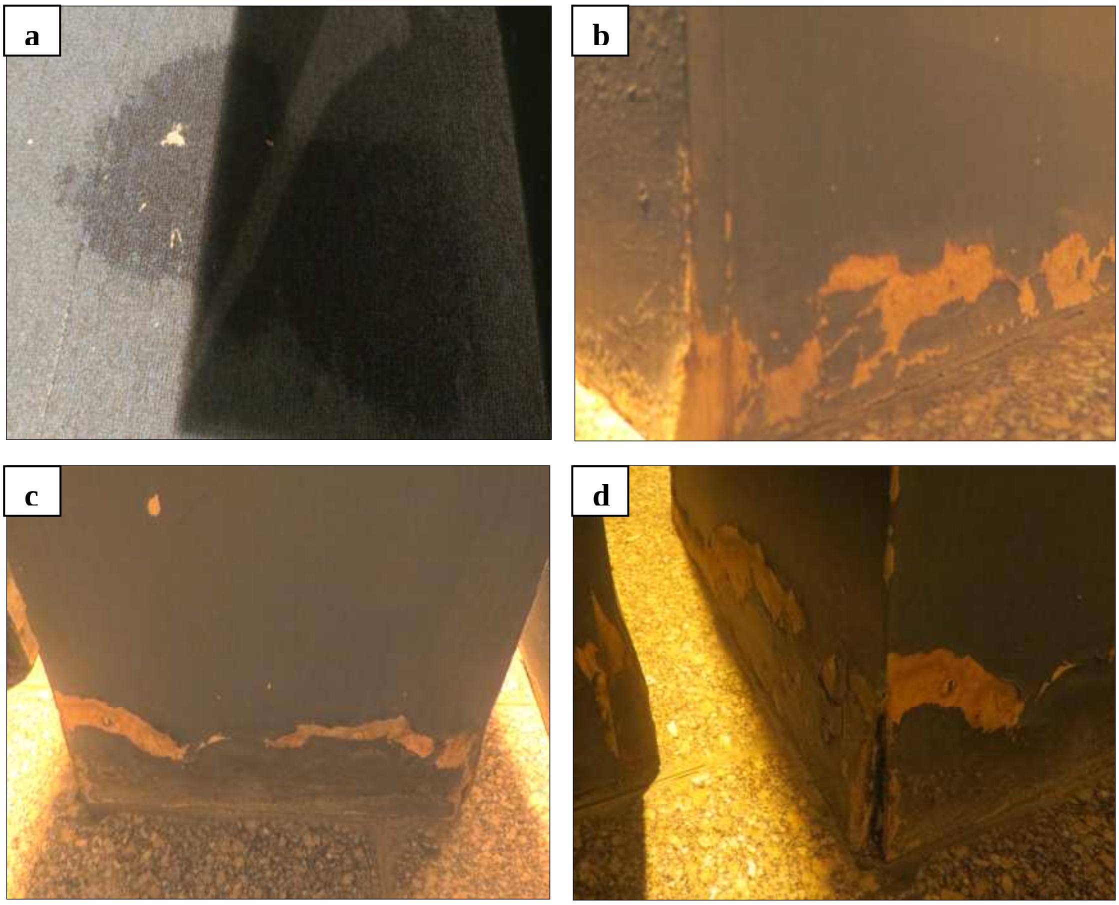

Figure (9) Shows deteriorated forms **a**. wet carpets, **b**., **c**., **d**., wooden bases under the artifacts

Regarding FTIR, the results of wave's length showed the different compounds and bonds on wood that affected the acceleration of its deterioration. According to Stefan, 2008 [12], the wave length 3336 O-H stretch the hydroxyl, 2938-2882 CH- stretch in methyl- and methylene groups, 1738 C=O stretch in un-conjugated ketones, carbonyls and in ester groups (frequently of carbohydrate origin) tell the less wave length which is deformation and primary alcohol. Now, it is clear that the type of wood basses used in Luxor museum can be easily exposed to damage, or work as catalyst for the deterioration of the archeological materials within the high RH value, temperature and the pollutants. XRF investigation results showed that the museum environment was infected by some factors of deterioration affecting their exhibits. They were mainly to the ambient air components that contained some aggressive elements such as MgO, AL_2O_3, K_2O, TiO_2 and CaO. This referred to the different components of plaster layers and paintings inside the museum. Particles entering the museum either by wind or by visitor's clothes and shoes were another resource of dust deposits. Damage could be caused at the moist dust surfaces interface, by chemical reactions, with gases or the harmful compounds in the deposited particles such as $CaSO_4$ and SO_2 [13]. Finally, Sio_2, quartz components in dust samples, possibly, entered the museum by air, or was formed by weathering of stone objects such as the exhibited statues in the open display. They could work as catalysts in the physical deterioration or chemical acceleration of the organic artifacts such as textiles. Because of the high ratio of RH value and gases, they were converted into acidic acids or alkaline solutions causing the hydrolytic breakdown of the textiles [14].

Conclusion

*Results prove that Luxor museum has a percentage of some pollutants, e.g. ammonia, organic acids and dust. They result from the upper uncovered parts of the interior walls of the museum and the air conditioning system that has no filters to prevent air pollutants. Dust and air pollutants with high temperature and relative humidity are responsible for the damage of the wooden bases, acceleration of organic materials and stone deterioration according to the XRF and the FTIR investigations. However, no Filters or monitor devices are used to minimize or control air pollutants inside the museum. Therefore, the current study recommends that: * Modern monitoring and measuring air pollutants devices, such as the passive indicator, used in the study, or the digital devices that can monitor more than one kind of pollutants are needed. * Prevention filter must be used. * Vacuum cleaners must be used to avoid the fin dust inside the museum.*

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